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RESEARCH, DEVELOPMENT, TEST & EVALUATION SECTION

Degradation of Pilot Reach Under G

William B. Albery, Ph.D.
Gregory F. Zehner, Ph.D.
Jeffrey A. Hudson, Ph.D.
Steve Bolia
Air Force Research Laboratory
Wright-Patterson AFB, Ohio

ABSTRACT

A pilot's ability to perform arm reach in the cockpit can be compromised by high-sustained acceleration (G). This research provides performance test data on reach to aircraft controls under several levels of sustained acceleration, especially negative G. Currently, Government requirements documents and aircraft manufacturers use locked harnesses at 1 G to simulate reach to controls at > 1 G. This research was conducted to determine the effects of reduced reach capability on pilot accommodation levels.

BACKGROUND AND RELEVANCE

High-performance fighter and attack aircraft currently in the USAF inventory (F-16, F-15, A-10, and soon, the F/A-22) are capable of achieving and sustaining G levels that exceed human tolerance. Recently, several aircraft accidents have been attributed to pilots in adverse G conditions having difficulty reaching controls. This research evaluated reach problems during negative G and reach assumptions made by aircraft manufacturers during cockpit design.

METHODS

The experiment was conducted in the Dynamic Environment Simulator (DES), a man-rated centrifuge in the Air Force Research Laboratory at Wright-Patterson AFB OH (Fig 1).

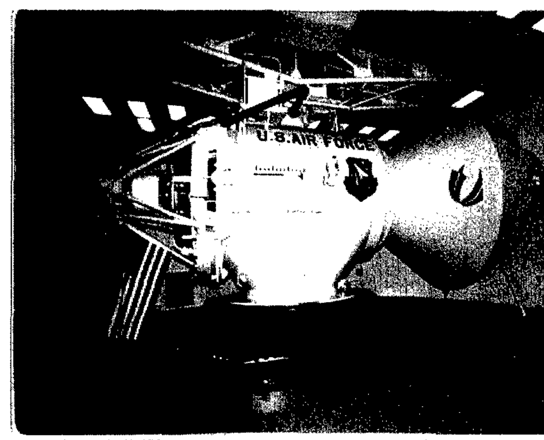

Figure 1. The Dynamic Environment Simulator centrifuge.

An approved ACES II facsimile seat was mounted in the cab of the DES. Two seat back conditions were tested, F-16 (30 deg) and F-15 (15 deg). Structures representative of aircraft switches were also installed in the cab (Fig 2).

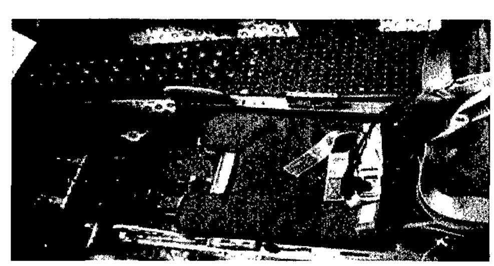

Figure 2. Top view of the ACES II-like ejection seat in the DES cab. The seated subject would be facing to the left. The switch panel is shown at the top, or on the right side of the seat.

These switches were used to evaluate reaches in three restraint harness conditions called "reach zones" as defined in Mil-Std 1333. Zone 1 reaches are attempted with a locked inertial reel and the pilot's shoulders must remain in contact with the seat. Emergency controls such as the ejection handles must be actuated in this restraint condition. Zone 2 reaches also are with locked reels, but the pilot is free to stretch as far as possible to actuate controls. Requirements documents typically include the primary flight controls as Zone 2 requirements. Zone 3 reaches are with unlocked reels and the pilot is permitted to lean forward to actuate all remaining controls in the cockpit. Listed below is an example from a previous USAF program.

Table 1. Example of USAF Reach Requirements

Required Controls Operable Under Zone 1 Conditions:

- All primary and secondary in-flight escape system controls, Inertial lock manual selector,Control stick, rudder pedals, and power control levers in neutral position

Required Controls Operable Under Zone 2 Conditions:

- Power control levers, full operational range
- Control stick, full operational range
- Trim override
- Rudder pedals, full operational range
- Emergency ground egress controls

Desired Controls Operable Under Zone 2 Conditions:

- Flaps
- Master caution cancel
- Nose gear steering engage and disable
- Toe brakes
- All power control lever (PCL) and hands on PCL and stick and throttle (HOTAS)
- Speed brake

SUBJECTS

The 17 subjects were all members of the Sustained Acceleration Panel, which is composed predominately of volunteer active duty Air Force members. These individuals qualify for the panel only after successfully completing an extensive medical evaluation and, in order to continue to participate, they must provide their ongoing informed consent. Simple anthropometric and strength measurements were made to rank order the subjects.

MEASUREMENTS

Baseline reach measurements at 1G were recorded for each subject. At each G level an exposure consisted of one Zone 2 reach (locked harness) to the switch row to determine the maximum forward reach possible, followed by a Zone 3 reach (unlocked harness with the subject leaning as far forward as possible) to the switch row. The switches were 2 inches apart. Both of these reaches were then repeated and averaged. The data reported are the differences between these two reaches. These reaches were performed with a locked restraint harness at - 1, +1, +2, +3 and +4 Gz. The same routine was then repeated with an unlocked harness. Prior to a G exposure the subject was instructed to initially place their hands in a stick and throttle position. They were then held at the particular G level until the switch was flipped or 10 seconds passed, whichever occurred first. As the subjects leaned forward to reach toward the controls, the effect of the positive G was to force their head into their lap. This made reaches difficult to accomplish. For that reason, subjects were allowed to "finger crawl" up the switch panel for support. Therefore, the time required to reach a control greatly increased.

EXPERIMENTAL PROCEDURE AND DATA ANALYSIS

Each subject was measured for anthropometric dimensions and simple strength testing. This was done to allow us to classify each subject relative to the sample. Data analysis included simple reach differences over the sample and their possible correlation with size and strength. Subjects performed maximum reaches toward a set of toggle switches on the right side of the ACES II.

RESULTS

The results are presented in Figure 3. F-15 data are in the graph on the left, F-16 on the right. On the Y-axis we have reach differences in inches with the reel locked and then unlocked. The X-axis is the Gz level ranging from –1 to +4 Gz. The mean difference of reach – from 1 Gz – is shown below each G level. The numbers shown on the graph are the number of subjects with that particular reach difference. The line segments connect means from each G level. The F-15 subjects were able to reach 8 to 12 inches further at 1, 2, 3, and 4 Gz (unlocked reel) than they could at 1 Gz locked. F-16 subjects were able to reach 6 to 10 inches further at 1, 2, 3, and 4 Gz (unlocked reel) than they could at 1 Gz locked. F-15 subjects were only able to reach, on average, 0.6 inch further when unlocked at –1 Gz than at +1 Gz locked. F-16 subjects were able to reach, on average, 4 inches further when unlocked at –1 Gz than at +1 Gz locked. The –1Gz reaches were physically very difficult.

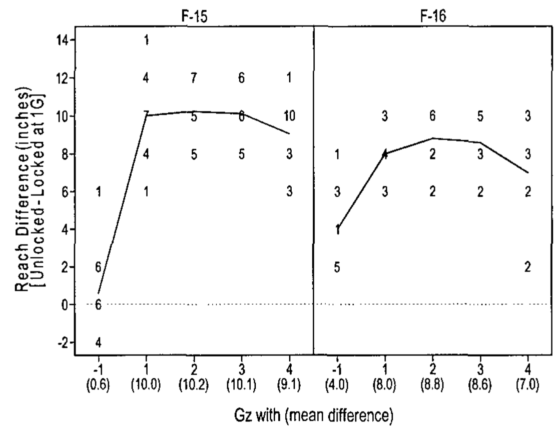

Figure 3. Reach as a Function of G in 15 and 30 Degree Seats

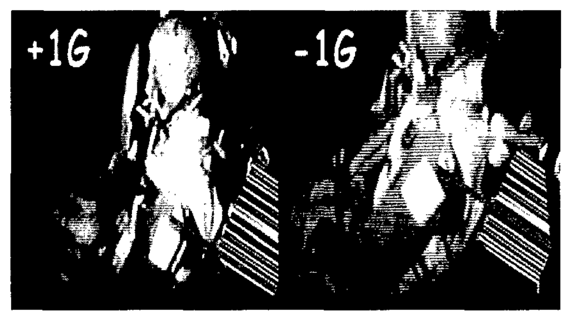

Figure 4. Shoulder Displacement from +1Gz to –1Gz

Also, as shown in Figure 4, when under negative G, our subjects averaged 3.8 inches of vertical shoulder displacement from the +1 Gz condition. In other words, the lap belt allowed them to "hang" nearly four inches out of the seat.

DISCUSSION

Quantifying arm reach in a cockpit becomes a multivariate body size question; that is, reach to a particular control is a function of shoulder height, shoulder width, and seat position (1,2). These factors, considered in total, are important because even though two pilots may have the same arm length, their other body measurements will most likely differ. While pilots do not typically lock their inertial reels while flying, locking the reels tests whether the pilot can control the aircraft during adverse G conditions or when there is an inadvertent or accidental restraint lock in flight. Typically, aircraft manufacturers assume the pilot must operate the inertial reel lock; emergency controls such as the ejection seat handles, and primary flight controls in this condition. Pilots who wear their harness loosely (in order to assist in "checking six"—meaning the ability to turn in their seats to look directly behind them for an adversary) can find themselves 'hanging' in the loosely fitting harness at the top of their canopy during a negative G maneuver and unable to reach these crucial controls.

The F-15 subjects were able to reach further down the switch panel than their F-16 counterparts because of the more vertical seat-back angle. The 15 deg seat back difference (15 vs. 30 deg) made it easier for the F-15 subjects to reach forward. The subjects were able to reach 6-12 inches further in the unlocked reel condition than in the locked condition for +1 through +4 Gz. For positive G the locked reel simulation of adverse G is not a good estimate for distance, at least up to 4 G, however, though not measured, the observed time necessary to reach these controls was dramatically increased under G > 1 than at +1Gz.

This part of the research may be repeated at a later date for G levels up to 9 G. There is a downward trend in the graph starting at 4 G and this may approach zero as G increases (Figure 3).

CONCLUSIONS

In this research we found pilot right-arm reach distance is unaffected by 2, 3, and 4 Gz, but the time required to reach the control is increased. However, during exposure to −1Gz, pilot arm reach is significantly reduced due to poor restraint by the lap belt. While the locked inertial reel rule-of-thumb to simulate high G effects in the cockpit appears to be inaccurate for positive G (at least up to + 4 Gz), the additional time requirements and the dramatic effect of negative G suggest that continued use of locked reels requirements is warranted for emergency controls that must be actuated very quickly.

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